REMARKS

The abstract and specification have been amended in order to correct grammatical and idiomatic errors contained therein. No new matter has been added.

Claim 1 has been amended in order to more particularly point out and distinctly claim the subject matter which Applicants regard as the invention. Specifically speaking, the lower limit of copper in Claim 1 has been limited to 1.7 wt.%. Support for this limitation can be found by Alloy E of Table 1 of the present specification. No new matter has been added. In order to respond to the Examiner's objection to Claim 3, Claim 3 has been canceled and replaced by newly presented Claim 6 which clearly requires that a hollow product be produced. Claim 6 also requires that the lower limit of copper be 1.7 wt.%. No new matter has been added.

The Examiner has objected to Claims 1-5 for not having actively recited method steps. U.S. patent law only requires that a method claim contain at least one active step. In the currently presented claims, the active step recited in the independent claims is <u>extruding</u> a billet of an aluminum alloy. As such, the currently presented claims clearly meet the requirements of 35 USC 101 with respect to method claims.

Claims 1-4 have been rejected under 35 USC 103(a) as being unpatentable over JP 07-041897A (JP '897) or U.S. Patent No. 5 503 690 to Wade. Applicants respectfully traverse these grounds of rejection and urge that the currently presented claims are clearly patentably distinguishable over the prior art cited by the Examiner.

The presently claimed invention is directed to a method of manufacturing a high-strength aluminum alloy extruded product which excels in corrosion resistance and stress corrosion cracking resistance. The method comprises the step of extruding a billet of a specified aluminum alloy containing specified component contents and which satisfy specified relationships, into a solid product by using a die having a

bearing length of at least 0.5 mm and the bearing length being no greater than five times the thickness of the solid product to be extruded.

Another embodiment of the present invention is directed to a method of manufacturing a high-strength aluminum alloy extruded hollow product which excels in corrosion resistance and stress corrosion cracking resistance. This method comprises the extrusion of a billet of aluminum alloy having a composition as discussed above for the first embodiment into a hollow product through the use of a porthole die or a bridge die in which the ratio of the flow speed of the aluminum alloy in a non-joining section with the flow speed of the aluminum alloy in a joining section in a chamber, where the billet reunites after entering a port section of the die in divided flows and subsequently encircling a mandrel, is controlled at 1.5 or less.

The methods of the present invention provide a product having a fibrous structure accounting for at least 60% or more in area fraction of the cross-sectional structure of the product. As discussed in the present specification, the instant invention was achieved after conducting extensive studies regarding the relationship between the characteristics of the extruded product, the composition of the material used to form the extruded product and dimensions of the die as well as various parts of flow guides, applicable when a product is extruded using a die alone or using a die together with a flow guide attached thereto. As stated above, by using an aluminum alloy of the claimed composition and conducting the extrusion under the conditions required in the claims, the extruded product is formed with a fibrous structure which accounts for 60% or more in area-fraction of the cross-sectional structure of the extruded product. It is respectfully submitted that the prior art cited by the Examiner does not disclose the presently claimed invention.

JP '897 discloses an aluminum alloy containing from 0.8 to 1.4% magnesium, 0.9 to 1.8% silicon, 0.7 to 1.2% copper and

0.1 to 5.0% zinc and, furthermore, containing a total 0.1 to 1.2% of at least one of manganese, chromium and zirconium, with the balance being aluminum and inevitable impurities. The upper limit of the copper content of 1.2% in this reference is much lower than the lower limit of 1.7% of copper required in the present claims. Additionally, there is no disclosure in this reference regarding the flow conditions under which the extrusion is conducted or the physical dimensions of the die in relationship to the thickness of the extruded product. Therefore, the secondary reference cited by the Examiner must provide the motivation to one of ordinary skill in the art to modify the primary reference in a manner that would yield the presently claimed invention. It is respectfully submitted that the secondary reference contains no such disclosure.

The Wade et al reference discloses a method of extruding a 6000-series aluminum alloy of a composition containing 0.6 to 1.2 wt.% silicon, 0.7 to 1.2 wt.% magnesium, 0.3 to 1.1 wt.% copper, 0.1 to 0.8 wt.% manganese, 0.05 to 0.25 wt.% zirconium, up to 0.5 wt.% iron, up to 0.15 wt.% chromium, up to 0.25 wt.% zinc, up to 0.10 wt.% titanium with the balance being aluminum and incidental impurities. Like the previously discussed reference, the lower limit of 1.17 wt.% copper of the present invention is much higher than the upper limit of 1.1 wt.% copper in the aluminum alloy disclosed in Wade et al. Additionally, as admitted by the Examiner, this reference has no disclosure with respect to the apparatus limitations of the die with respect to the thickness of the extruded product and the flow speed of the extruded aluminum alloy. As such, Applicants respectfully submit that this reference, in combination with the previously discussed reference, does not even make a showing of prima facie obviousness under 35 USC 103(a). Moreover, Applicants respectfully submit that objective evidence of the unobviousness of the presently claimed invention is of record in the present application.

In Comparative Example 1, aluminum alloys having compositions outside of the present claims are disclosed. As shown in Table 4, these alloys had inferior properties as compared to those of the present invention. Likewise, Comparative Examples 2-4 should be compared with Examples 2-4 in the present specification. As can be seen by the results contained in the tables, the aluminum alloys of the present invention clearly have superior properties when compared with the aluminum alloys of the Comparative Examples, which fall within the scope of the disclosures of the references cited by the Examiner. Therefore, Applicants respectfully submit that the patentability of the presently claimed invention has been established.

The Examiner is respectfully requested to reconsider the present application and to pass it to issue.

Respectfully submitted,

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METHOD OF MANUFACTURING HIGH-STRENGTH ALUMINUM ALLOY EXTRUDED PRODUCT EXCELLING IN CORROSION RESISTANCE AND STRESS CORROSION CRACKING RESISTANCE

ABSTRACT OF THE DISCLOSURE

A method of manufacturing a high-strength aluminum alloy extruded product which excels in corrosion resistance and stress corrosion cracking resistance, and is suitably used in applications as structural materials for transportation equipment such as automobiles, railroad carriages, and aircrafts. The method includes extruding a billet of an aluminum alloy ~~comprising~~containing 0.5% to 1.5% of Si, 0.9% to 1.6% of Mg, 0.8% to 2.5% of Cu, while satisfying the following equations (1), (2), (3), and (4),

$$3 \leq Si\% + Mg\% + Cu\% \leq 4 \quad (1)$$

$$Mg\% \leq 1.7 \times Si\% \quad (2)$$

$$Mg\% + Si\% \leq 2.7 \quad (3)$$

$$Cu\%/2 \leq Mg\% \leq (Cu\%/2) + 0.6 \quad (4)$$

and further ~~comprising~~containing 0.5% to 1.2% of Mn, with the balance being Al and unavoidable impurities, into a solid product by using a solid die, or into a hollow product by using a porthole die or a bridge die, thereby obtaining the solid product or the hollow product in which a fibrous structure accounts for 60% or more ~~in~~of an area-fraction of the cross-sectional structure of the product.

~~TITLE OF THE INVENTION~~

METHOD OF MANUFACTURING HIGH-STRENGTH ALUMINUM ALLOY EXTRUDED PRODUCT EXCELLING IN CORROSION RESISTANCE AND STRESS CORROSION CRACKING RESISTANCE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a method of manufacturing a high-strength aluminum alloy extruded product excelling in corrosion resistance and stress corrosion cracking resistance. More particularly, the present invention relates to a method of manufacturing a high-strength aluminum alloy extruded product excelling in corrosion resistance and stress corrosion cracking resistance which is suitable in application as structural materials for transportation equipment such as automobiles, railroad carriages, and aircrafts.

Description of Background Art

In recent years, emission regulations have been tightened from the viewpoint of protection of the global environment. In the field of manufacture of structural members and components for transportation equipment such as automobiles, the reduction of vehicle weight has been vigorously pursued to save fuel consumption and hence to decrease the emission of carbon dioxide and other noxious gases. ~~One of~~An effective means to reduce the vehicle weight is the use of aluminous materials instead of conventionally used ferrous materials.

The 6000 series (Al-Mg-Si) aluminum alloys as represented by an AA6061 alloy and AA6063 alloy are widely employed in practical applications in transportation equipment components due to excellent workability, easiness of production, and excellent corrosion resistance. However, since the 6000 series alloys have disadvantages in strength in comparison

with high-strength aluminum alloys such as the 7000 series (Al-Zn-Mg) alloys and the 2000 series (Al-Cu) alloys, an increase in the strength of the 6000 series aluminum alloys has been attempted. For example, an AA6013 alloy, AA6056 alloy, AA6082 alloy, and the like have been developed.

These alloys possess improved strength in comparison with the conventional AA6061 alloy or the like. However, further progress in the reduction of the vehicle weight is making requirements for thinner and lighter materials even more demanding. Since there still have been cases where the above alloys are not wholly satisfactory in terms of strength, corrosion resistance, and stress corrosion cracking resistance, there is proposed an aluminum alloy comprising 0.5 to 1.5% of Si, 0.9 to 1.5% of Mg, 1.2 to 2.4% of Cu, wherein the composition of Si, Mg, and Cu satisfies the conditional equations $3 \leq Si\% + Mn\% + Cu\% \leq 4$, $Mg\% \leq 1.7 \times Si\%$, and $Cu\%/2 \leq Mg\% \leq (Cu\%/2) + 0.6$, and further comprising 0.2 to 0.4% of Cr, while limiting Mn as an impurity at 0.05% or less, with the balance being Al and unavoidable impurities (Japanese Patent Application Laid-open No. 8-269608).

However, this aluminum alloy is mainly used as a sheet material and has the disadvantage of inferior extrudability and inferior characteristics of extrusions in extrusion application, particularly when extruded into a hollow profile by using a porthole die or a spider die. In order to overcome this problem, one of the inventors of the present invention, together with other inventors, reviewed the above composition and proposed an Al-Cu-Mg-Si alloy extruded product for application in structural members of transportation equipment (Japanese Patent Application Laid-open No. 10-306338). This aluminum alloy extruded product is excellent in extrudability into a hollow profile and is characterized in that, when a tensile test is conducted for the weld joints inside the

extruded hollow cross section by applying a tensile stress in the direction perpendicular to the extrusion direction, the aluminum alloy extruded product fractures at locations other than the weld joints.

However, if the above aluminum alloy extruded product is used in a reduced thickness, the aluminum alloy extruded product is not entirely capable of providing the required strength. In order to improve the characteristics of the above Al-Cu-Mg-Si alloy extruded product, one of the inventors of the present invention together with other inventors further proposed to add Mn to the Al-Cu-Mg-Si alloy and to control the thickness of the crystal layer of the Al-Cu-Mg-Si alloy extruded product, thereby ~~to provide~~providing a high-strength alloy extruded product having excellent corrosion resistance (Japanese Patent Application Laid-open No. 2001-11559). However, this aluminum alloy exhibits poor extrudability in comparison with conventional alloys such as the AA6063 alloy due to high deformation resistance. In particular, when successive billets are supplemented for a continuous extrusion of a solid product, it is necessary to provide a flow guide at the front of the solid die. However, this aluminum alloy suffers from deficiencies such as extrusion cracking occurring at the corners of the extruded product and a tendency for forming a coarse surface grain structure, thereby causing a deterioration in strength as well as in stress corrosion cracking resistance.

Moreover, in the case where a hollow product is extruded by using a porthole die or a bridge die, this aluminum alloy also presents problems such as extrusion cracking and a tendency for forming a coarse grain structure along the joints, thereby causing a deterioration in strength, corrosion resistance, and stress corrosion cracking resistance.

The present invention has been achieved after extensive experiments and investigations conducted in an attempt to solve the above-described problems associated with high-strength aluminum alloy extruded products, including studies concerning the relationship between the characteristics of the extruded product and dimensions of the die as well as various parts of flow guides, applicable when a solid product is extruded using a solid die alone or using a solid die together with a flow guide attached thereto, and studies concerning the relationship between the characteristics of the extruded product and the difference in flow speeds of the aluminum alloy inside the extrusion die, applicable when a hollow product is extruded by using a porthole die or a bridge die. Accordingly, an object of the present invention is to provide a method of manufacturing an aluminum alloy extruded product excelling in corrosion resistance, stress corrosion cracking resistance, and strength, as achieved by effectively preventing the occurrence of extrusion cracking or formation of a coarse grain structure in the extruded product.

SUMMARY OF THE INVENTION

In order to achieve the above object, the present invention provides a method of manufacturing a high-strength aluminum alloy extruded product excelling in corrosion resistance and stress corrosion cracking resistance, the method comprising extruding a billet of an aluminum alloy comprising (hereinafter, all compositional percentages are by weight), 0.5% to 1.5% of Si, 0.9% to 1.6% of Mg, 0.8% to 2.5% of Cu, while satisfying the following equations (1), (2), (3), and (4),

$$3 \leq Si\% + Mg\% + Cu\% \leq 4 \quad (1)$$

$$Mg\% \leq 1.7 \times Si\% \quad (2)$$

$$Mg\% + Si\% \leq 2.7 \quad (3)$$

$$Cu\%/2 \leq Mg\% \leq (Cu\%/2) + 0.6 \qquad (4)$$

and further comprising 0.5% to 1.2% of Mn, with the balance being Al and unavoidable impurities, into a solid product by using a solid die in which a bearing length (L) is 0.5 mm or more and the bearing length (L) and a thickness (T) of the solid product to be extruded have a relationship defined by L ≤ 5T, thereby obtaining ~~the~~a solid product in which a fibrous structure accounts for 60% or more in area-fraction of the cross-sectional structure of the solid product.

In this method of manufacturing a high-strength aluminum alloy extruded product excelling in corrosion resistance and stress corrosion cracking resistance, a flow guide may be provided at a front of the solid die, an inner circumferential surface of a guide hole of the flow guide being separated from an outer circumferential surface of an orifice continuous with the bearing of the solid die at a distance of 5 mm or more, and the thickness of the flow guide being 5% to 25% of the diameter of the billet.

The present invention also provides a method of manufacturing a high-strength aluminum alloy extruded product excelling in corrosion resistance and stress corrosion cracking resistance, the method comprising extruding a billet of the above aluminum alloy into a hollow product by using a porthole die or a bridge die in which ~~a~~the ratio of the flow speed of the aluminum alloy in a non-joining section to the flow speed of the aluminum alloy in a joining section in a chamber, where the billet reunites after entering a port section of the die in divided flows and subsequently ~~encircling~~encircles a mandrel, is controlled at 1.5 or less, thereby obtaining the hollow product in which a fibrous structure accounts for 60% or more in area-fraction of the cross-sectional structure of the hollow product.

In the above method of manufacturing a high-strength aluminum alloy extruded product excelling in corrosion resistance and stress corrosion cracking resistance, the aluminum alloy may further comprise at least one of 0.02% to 0.4% of Cr, 0.03% to 0.2% of Zr, 0.03% to 0.2% of V, and 0.03% to 2.0% of Zn.

In the above method of manufacturing a high-strength aluminum alloy extruded product excelling in corrosion resistance and stress corrosion cracking resistance, the method may comprise a homogenization step wherein a billet of the aluminum alloy is homogenized at 450°C or more and cooled at an average cooling rate of 25°C/h or more from the homogenization temperature to at least 250°C, an extrusion step wherein the homogenized billet of the aluminum alloy is extruded at a temperature of 450°C or more, a press quenching step wherein the extruded product is cooled to a temperature of 100°C or less at a cooling rate of 10°C/sec or more in a state in which a surface temperature of the extruded product immediately after the extrusion is maintained at 450°C or more, or a quenching step wherein the extruded product is subjected to a solution heat treatment at a temperature of 450°C or more and cooled to a temperature of 100°C or less at a cooling rate of 10°C/sec or more, and an aging step wherein the quenched product is heated at a temperature of 150°C to 200°C for 2 to 24 hours.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view illustrating a solid die and a flow guide used in the present invention.

~~FIG. 2 is a view~~FIGS. 2(a)-(f) are views illustrating a thickness T of a solid extruded product of the present invention.

FIG. 3 is a front view illustrating a male die section of a porthole die used in the present invention.

FIG. 4 is a back view illustrating a female die section of a porthole die used in the present invention.

FIG. 5 is a vertical cross-sectional view illustrating a porthole die built by coupling the male die section shown in FIG. 3 and the female die section shown in FIG. 4 together.

FIG. 6 is an enlarged view of a forming section of the porthole die shown in FIG. 5.

FIG. 7 is a graph illustrating a relationship between a ratio of a chamber depth D to a bridge width W of a porthole die and a ratio of metal flow speeds in the die.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The significance and reasons for the limitations of the alloy components of the aluminum alloy of the present invention are described below.

Si plays a role ~~to improve~~in improving the strength of the aluminum alloy by precipitating Mg_2Si in combination with coexistent Mg. The preferred range for the Si content is 0.5% to 1.5%. If the Si content is less than 0.5%, the improvement effect may be insufficient. If the Si content exceeds 1.5%, the corrosion resistance may ~~be decreased~~decrease. The more preferred range for the Si content is 0.7% to 1.2%.

Mg improves the strength of the aluminum alloy by precipitating Mg_2Si in combination with coexistent Si, and also by precipitating fine particles of $CuMgAl_2$ in combination with coexistent Cu. The preferred range for the Mg content is 0.9% to 1.6%. If the Mg content is less than 0.9%, the improvement in strength may be insufficient. If the Mg content exceeds 1.6%, the corrosion resistance may ~~be decreased~~decrease. The more preferred range for the Mg content is 0.9% to 1.2%.

Cu is an element that contributes to an improvement in strength in the same manner as Si and Mg. The preferred range for the Cu content is 0.8% to 2.5%. If the Cu content is less than 0.8%, the improvement in strength may be insufficient. If the Cu content exceeds 2.5%, it gives rise to a reduced corrosion resistance as well as difficulty in manufacturing. The more preferred range for the Cu content is 0.9% to 2.0%.

Mn plays an important role in providing a high strength by restricting recrystallization during a hot working process and thereby forming a fibrous structure. The preferred range for the Mn content is 0.5% to 1.2%. If the Mn content is less than 0.5%, the effect in restricting the recrystallization may become insufficient. If the Mn content exceeds 1.2%, it gives rise to formation of coarse intermetallic compounds as well as a deterioration ~~of~~in hot workability. The more preferred range for the Mn content is 0.6% to 1.0%.

The high-strength aluminum alloy of the present invention comprises Si, Mg, Cu, and Mn as the essential components, in which the conditional equations (1) to (4) must be satisfied concerning the mutual relationships between the Si, Mg, and Cu contents. This enables the quantity and distribution of intermetallic compounds produced to be adequately controlled to provide an aluminum alloy with a high strength and corrosion resistance in a well-balanced manner. If the combined content of the essential alloying components Si, Mg, and Cu is less than 3.0%, the desired strength cannot be obtained. If the combined content exceeds 4%, the corrosion resistance may ~~be decreased~~decrease. If the combined content of Mg and Si exceeds 2.7%, it gives rise to an inferior corrosion resistance as well as a deterioration in ductility.

Cr, Zr, V, and Zn that may be added to the aluminum alloy of the present invention as optional components reduce the crystal grain size. If the content of Cr, Zr, V, and Zn is

less than the lower limit, the above effect may become insufficient. If the content exceeds the upper limit, coarse intermetallic compounds may ~~be formed~~form, whereby the mechanical characteristics, such as elongation and toughness, of the resulting extruded products may be adversely affected. The aluminum alloy of the present invention may contain a small amount of Ti or B, that is normally added to provide a finer ingot grain structure, without harming the features of the present invention.

Extrusion of a solid product according to the method of the present invention is described below. An aluminum alloy having a given composition is cast into a billet by conventional semi-continuous casting and extruded into a solid product by hot working using a solid die. FIG. 1 illustrates a configuration of equipment used to extrude the solid product. In the case of extruding a long product, a flow guide 4 is provided at the front of a solid die 1 so that successive billets can be used for continuous extrusions.

An aluminum alloy billet 9, charged in an extrusion container 7, is pushed by an extrusion stem 8 in the direction indicated by the arrow in the illustration and forced into an orifice 3 of the solid die 1 after entering a guide hole 5 of the flow guide 4. The aluminum alloy billet 9 is extruded into a solid product 10 as its profile is formed by a bearing face 2 of the solid die 1.

In an extrusion procedure for a solid product, the shape of the extruded product is defined by the bearing of the solid die, with the bearing length L having an effect on the characteristics of the extruded product. According to the present invention, it is essential that the bearing length L be set at 0.5 mm or more (i.e. $0.5mm \le L$), and the relationship between the bearing length L and the thickness T as measured for the resulting solid product 10 in the ~~cross~~

~~section~~cross-section perpendicular to the extrusion direction (illustrated in FIG. 2) be set at L ≤ 5T, and more preferably at L ≤ 3T. It has been found that by performing the extrusion procedure using a solid die having the dimensions described above, a solid extruded product can be manufactured so that a fibrous structure accounts for 60% or more in area-fraction of the cross-sectional structure of the solid product. A solid extruded product having a fibrous structure at 60% or more, and more preferably 80% or more in area-fraction of the cross-sectional structure excels in strength, corrosion resistance, and stress corrosion cracking resistance. If the area-fraction of the recrystallized structure exceeds 20%, it gives rise to a tendency to cause intergranular corrosion. If the area-fraction of the recrystallized structure exceeds 40%, intergranular corrosion exceeding the allowable maximum may occur. The thickness T refers to the largest value of various measurements given for a solid extruded product in the ~~cross section~~cross-section perpendicular to the extrusion direction, as illustrated in FIG. 2.

If the bearing length is less than 0.5 mm, fabrication of the bearing becomes difficult and elastic deformation of the bearing may give rise to inconsistency in dimensional accuracy. If the bearing length is greater than 5T, recrystallization tends to occur in the surface layer of the cross-sectional structure of the resulting solid product.

In the case where the flow guide 4 needs to be provided at the front of the solid die 1, it is essential that an inner circumferential surface 6 of a guide hole 5 inside the flow guide 4 be separated from the outer circumferential surface of an orifice 3 of the solid die 1 at a distance of 5 mm or more (i.e. A ≥ 5 mm), and the ~~thickness~~length B of the flow guide 4 be 5% to 25% of the diameter of the billet 9 (i.e. B = D × 5% to 25%). Applying the above-described flow guide in

combination with a solid die having the above-described bearing dimensions ensures that a fibrous structure accounts for 60% or more in an area-fraction of the cross-sectional structure of the resulting solid product to provide a solid extruded product excelling in strength, corrosion resistance, and stress corrosion cracking resistance.

If the distance A between the inner circumferential surface 6 of the guide hole 5 inside the flow guide 4 and the outer circumferential surface of the orifice 3 of the solid die 1 is less than 5 mm, the degree of working inside the guide hole 5 becomes excessively high, thereby causing recrystallization to occur in the surface layer of the resulting solid product. If the length B of the flow guide 4 is less than 5% of the diameter D of the billet 9, the flow guide 4 may have insufficient strength and therefore a tendency to ~~be deformed~~deform. If the length B of the flow guide 4 is greater than 25% of the diameter D of the billet 9, the degree of working inside the guide hole 5 becomes excessively high, thereby producing cracking in the resulting solid product to cause the strength or elongation to substantially deteriorate. Additionally, for a solid extruded product having a rectangular profile, cracking at the corners or recrystallization in the surface layer can be avoided by rounding off the corners at a radius of 0.5 mm or more.

Extrusion of a hollow product according to the method of the present invention is described below. An aluminum alloy having a given composition is cast into a billet by conventional semi-continuous casting and extruded into a hollow product by hot working using a porthole die or a bridge die. FIGS. 3 and 4 illustrate a configuration of a porthole die. FIG. 3 is a front view of a male die section 12 observed from a mandrel 15. FIG. 4 is a back view of a female die section 13 equipped with a die section 16 to house the mandrel

15. FIG. 5 is a vertical cross-sectional view of a porthole die 11 formed by coupling the male die section 12 and the female die section 13 together. FIG. 6 is an enlarged view of a forming section shown in FIG. 5.

The porthole die 11 comprises the male die section 12 equipped with a plurality of port sections 14 and the mandrel 15, and the female die section 13 equipped with the die section 16, which are coupled together as shown in FIG. 5. A billet pushed by an extrusion stem (not shown) enters the port sections 14 of the male die section 12 in divided flows which then reunite (join together) in a chamber 17 while encircling the mandrel 15 in the chamber 17. Upon ~~exit~~exiting from the chamber 17, the billet receives forming work by a bearing section 15A of the mandrel 15 for its inner surface and by a bearing section 16A of the die section 16 for its outer surface to produce a hollow product. A bridge die basically has a configuration similar to that of the porthole die except its male die section is modified in consideration of the metal flow within the die, extrusion pressure, extrudability, and the like.

In this case, the aluminum alloy (metal) after entering and exiting the port sections 14 moves into the chamber 17 where the aluminum alloy also flows around the back of bridge sections 18 located between the two port sections 14 to reunite (join). It is observed here that the flow speed of the metal in the non-joining section, where the metal flows from one port section 14 directly out to the die section 16 without engaging in the joining action with the metal flow from another port section 14, is greater than the flow speed of the metal in the joining section, where the metal that exited from one port section 14 flows around the back of the bridge section 18 and engages in the welding action with the metal flow from another port section 14, thereby resulting in

a difference in the metal flow speeds inside the chamber 17. It should be noted here that, while FIG. 3 and FIG. 4 illustrate a porthole die having two port sections and two bridge sections, the above-mentioned observation applies equally to a porthole die having three or more port sections and three or more bridge sections.

As a result of extensive experiments and investigations conducted on the relationship between the difference in the metal flow speeds inside the die and the characteristics of the extruded hollow product, the present inventors have found that extrusion cracking and the growth of a coarse grain structure at the joints are caused by the above-described difference in metal flow speeds, and that it is essential to perform the extrusion while restricting the ratio of the metal flow speed in the non-joining section to the metal flow speed in the joining section of the chamber 17 at 1.5 or less (i.e. (flow speeding non-joining section)/(flow speed in joining section) ≤ 1.5) in order to prevent these problems. Maintaining the ratio of metal flow speeds within the above limits ensures that a fibrous structure accounts for 60% or more in an area-fraction of the cross-sectional structure of the resulting solid product to provide a solid extruded product excelling in strength, corrosion resistance, and stress corrosion cracking resistance. A solid extruded product having a fibrous structure at 60% or more in the area-fraction of the cross-sectional structure excels in strength, corrosion resistance, and stress corrosion cracking resistance. If the area-fraction of the recrystallized structure exceeds 20%, it gives rise to a tendency to cause intergranular corrosion. If the area-fraction of the recrystallized structure exceeds 40%, intergranular corrosion exceeding the allowable maximum may occur.

In order to perform extrusion work while restricting the ratio of the metal flow speed in the non-joining section to the metal flow speed in the joining section of the chamber 17 ~~at~~to 1.5 or less, a porthole die designed in such a way that the ratio of the chamber depth D (illustrated in FIGS. 5 and 6) to the bridge width W (illustrated in FIG. 3) is adequately adjusted is used, for example. FIG. 7 illustrates an example of relationships between the D/W ratio and the ratio of the flow speed in the non-joining section to the flow speed in the joining section.

A preferred method of manufacturing the aluminum alloy extruded product of the present invention is described below. A molten aluminum alloy having the above composition is cast into a billet by semi-continuous casting, for example. The resulting billet is homogenized at a temperature not lower than 450°C but below its melting point, and cooled at an average cooling rate of 25°C/h or more from the homogenization temperature to at least 250°C.

If the homogenization temperature is less than 450°C, a sufficient homogenization effect may not be obtained and dissolution of solute elements becomes inadequate, thereby making it difficult to impart sufficient strength to the product when press quenching, in which the extruded product is water-cooled immediately after extrusion, is performed to obtain the desired strength. By cooling the material to 250°C at an average cooling rate of 25°C/h or more, solute elements dissolved by the homogenization treatment are kept in the solid solution state to achieve a superior strength. If the cooling rate is less than 25°C/h, solute elements dissolved by the homogenization step may precipitate and coagulate to form coarse grains, thereby making it difficult to impart sufficient strength to the product, since such elements, once coagulated, are hard to redissolve in the solid solution. The

more preferred cooling rate is 100°C/h or more to consistently achieve the desired strength.

After completion of the homogenization step, the extrusion billet is extruded by a hot working step by heating the billet to 450°C or more to obtain an extruded product. If the temperature of the extrusion billet before extrusion is less than 450°C, dissolution of the solute elements may become insufficient, thereby making it difficult to impart sufficient strength to the product by press quenching. If the temperature of the extrusion billet before extrusion exceeds the melting point thereof, cracking may occur during the extrusion operation.

In the case where press quenching is performed, the surface temperature of the extruded product immediately after extrusion is maintained at 450°C or more and cooled to a temperature of 100°C or less at a cooling rate of 10°C/sec or more in the press quenching step. If the surface temperature of the extruded product is less than 450°C, a quenching delay in which solute elements precipitate may occur, thereby making it impossible to obtain the desired strength. If the cooling rate is less than 10°C/sec, precipitation of solute elements occurs during the cooling step to make it impossible to obtain the desired strength and to cause the corrosion resistance to deteriorate. The more preferred cooling rate is 50°C/sec or more.

The extruded product may be treated according to a conventional quenching procedure in which the extruded product is subjected to a solution heat treatment at a temperature of 450°C or more in a heat treatment furnace, such as a controlled-atmosphere furnace or a salt-bath furnace, and cooled to a temperature of 100°C or less at a cooling rate of 10°C/sec or more. If the heating temperature during the solution heat treatment is less than 450°C, dissolution of

solute elements becomes inadequate to make it impossible to obtain the desired strength. If the cooling rate is less than 10°C/sec, precipitation of solute elements occurs during the cooling step in the same manner as in press quenching, thereby making it impossible to obtain the desired strength and causing the corrosion resistance to deteriorate. The more preferred cooling rate is 50°C/sec or more.

The quenched extruded product is annealed at a temperature of 150°C to 200°C for 2 to 24 hours to obtain a finished product. If the annealing temperature is less than 150°C, the annealing process may take more than 24 hours in order to obtain sufficient strength, thereby making it undesirable from the standpoint of industrial productivity. If the annealing temperature exceeds 200°C, the maximum achievable strength may become lower. Moreover, if the duration of annealing is less than 2 hours, it is impossible to obtain sufficient strength, whereas an annealing duration of over 24 hours causes the strength to deteriorate.